Current knowledge of equine water treadmill exercise: what can we learn from human and canine studies?

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None to declare.

Abstract

Equine water treadmills are increasingly being found in research and therapy centres and private competition yards. However the programmes incorporating water treadmill exercise for training and rehabilitation of horses are mainly based on anecdotal evidence due to the lack of scientific evidence available. This review aims to evaluate what is currently known about water treadmill exercise for horses drawing on what is known from human and canine investigations. Studies of water treadmill exercise have demonstrated that water depth, temperature and speed have a significant effect on physiological responses in humans. The physiological studies in horses show many similarities to human responses with much evidence demonstrating that water treadmill exercise is an aerobic form of exercise which does not appear to induce improvement in aerobic capacity when used within training programmes. Equine and canine studies have shown that water depth can have a significant effect on the biomechanical responses to water treadmill exercise but little is known about the effect of different speeds at the various water depths. Key areas we would recommend for future research are: how combinations of water depth and speed alter equine biomechanics compared to overland exercise, determination of long-term benefits of water treadmill exercise and how to use water treadmill for rehabilitation for horses with specific injury.

Keywords: Equine, Water Treadmill, Physiological responses, Biomechanical responses

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1. Introduction

The water treadmill (WT) is a popular tool to use within training and rehabilitation programmes of horses, humans and dogs. A number of factors need to be considered prior to including WT exercise in an equine training or rehabilitation programme. Horses should be prepared appropriately for the session and habituated to the equipment and to the different conditions it may encounter whilst using it, including the presence of water, variations in speed, and variations in water depth. No single condition will suit all horses so protocols need to be developed on an individual basis depending on the specific outcome for that horse.

The extent of the literature relating to any type of exercise in water is vast, but for the purpose of this review we will consider WT exercise only. The majority of the literature relates to human WT exercise with rather less relating to horses and dogs. Evident from the human literature is the complexity of physiological and biomechanical responses, depending upon whether subjects are healthy or unhealthy, trained or untrained, young or elderly and depending upon the water depth, water temperature and belt speed. In this review we aim to evaluate what is currently known about WT exercise for horses in terms of: 1. habituation to WT exercise; 2. physiological responses; 3. biomechanical responses and 4. potential as a rehabilitation tool whilst drawing on what is known about human and canine WT exercise. As a result of this evaluation we also aim to identify the most useful future directions for equine WT research.

2. Habituation to water treadmill exercise.

When a horse is worked on a WT, there is an initial period where the horse is learning and habituating to the process and equipment. This requires adaptation, physically and mentally, for the horse experiencing a new environment. To our knowledge this process has not been investigated in humans or dogs but has been documented in horses. Anecdotally, in sound uninjured dogs it takes two sessions in deep water for the dogs to reach a steady locomotion pattern (Handley-Howard, pers. comm.).

Habituation to WT exercise in the horse has been examined with respect to both physiological [1] and stride variables [2]. A study concluded that a minimum of two 15 minute habituation sessions were needed to achieve steady state heart rates in horses walking on a WT [1]. During habituation to walking and trotting on a land high speed treadmill, stride frequency decreases to steady state, initially being high with short, wide steps taken [3]. Scott et al [2] measured stride length and frequency in horses during an initial habituation period on a WT. Horses showed erratic changes in stride frequency, this is in contrast to the gradual decrease in frequency on a land treadmill [3] during the first three sessions but became constant by the fourth session. This could be due to horses having to negotiate two features (a belt and an increase in water depth with each consecutive session) when on a WT and just one feature (a belt) when on a land treadmill.

It appears that during habituation to WT exercise, heart rate reaches a steady state earlier than biomechanical variables and that three or four sessions are required for these variables to become constant. These findings mirror those of habituation to land treadmill exercise [4].

3. Physiological responses to water treadmill exercise

3.1 Acute physiological responses to water treadmill exercise.

Human studies demonstrate that oxygen uptake and heart rate are linearly related at low speed (walking) in high water [5] but not at higher speeds (running) in lower water (water up to waist depth) [6]. At low speeds, walking in water poses similar metabolic costs to walking on land, but increases in speed of walking particularly in lower water can increase oxygen consumption over and above the equivalent speed on land [5, 6, 7]. Heart rate–speed relationships during water walking are also temperature dependant, with greater heart rates at any given speed in higher water temperatures having been demonstrated in both humans and horses [5, 6, 8]. Oxygen consumption of horses during WT exercise has not been measured, but several studies have used heart rate as a measure of workload [1, 2, 9, 10, 11]. A wide range of speeds (range: 0.8-5.5 m/s), water depths (range: baseline to 80% wither height), frequencies (daily or three times a week) and durations (range: 15-44 minutes) have been utilised within studies, perhaps reflecting the very different ways in which users currently incorporate WT exercise within training. Regardless of the study design, all the evidence relating to indicators of energy utilisation suggests that WT exercise is an aerobic form of exercise. Walking at 0.9 m/s at ulna depth resulted in heart rates up to 65 beats/min [2], which are not dissimilar to those measured during overland walking. Lindner et al [9] had 10 German warmblood horses trot on a WT at 5.5 m/s whilst the water depth was increased every five minutes from 20% of wither height to 77% of wither height in five increments. There was no significant increase in heart rate with water depth. In fact, heart rate at higher depths (50% wither height and above) was lower than in shallower water. The plateau in heart rate is thought to reflect a plateau in workload due to increasing buoyancy (and effective reduction in bodyweight) and/or the contribution of increasing hydrostatic pressure in improving venous return and subsequent stroke volume [9]. The evidence thus dispels the commonly held belief amongst WT users that higher water means harder work.

Studies in humans have also demonstrated either a plateau or a reduction in exercising heart rates with increasing water depth, For example, a study in which physically active, trained individuals exercised on a WT at increasing depths and speeds (whilst walking and jogging) [6] showed that at speeds above 80 m/min (1.3 m/s), the highest water depth (waist depth) did not elicit the highest heart rates. At the peak speed in that study (2.7 m/s), heart rate in waist depth water was 30 beats/min lower than thigh depth water (187 beats/min).

During overland exercise or on a high speed land treadmill there is a linear relationship between speed and heart rate up to maximal heart rate [12]. However, heart rate-speed relationships during WT exercise are non-linear in both humans and horses [5, 6, 9] with the effect of speed on heart rate dependent on water depth. Lindner et al [9] trotted horses on a WT at increasing speeds (from 3.5 to 5.5 m/s) but constant water depths (either 10, 50 or 80% of wither height). Only at lower water depths (10 and 50%) did an increase in speed result in an increase in heart rate. Once water depth was 80% of wither height, heart rate remained constant throughout the test, and was between 120 and 140 beats/min at all depths and speeds. So high water does not appear to constitute the highest intensity of exercise in a WT, and increases in speed do not appear to bring about increases in heart rate once water depth is high (i.e. once the limbs are submerged). No studies have demonstrated heart rates above 140 beats/min, so WT exercise is lower intensity exercise than galloping overland (160 beats/min plus) or swimming [13].

Heart rate at any given speed and depth of water is also influenced by water temperature. Human studies [5, 6] have shown that heart rate increases more rapidly with water depth/speed in higher water temperatures, as the need to dissipate heat adds to the load on the cardiovascular system. An equine study investigated the association between water temperatures and heart rate in horses walking on a WT in water temperatures of 13, 16 and 19 ^{0}C with water at the depth of the scapulohumeral joint [8]. Heart rate increased with water temperature. Results indicated that although there appeared to be net heat loss at 13 and 16 ^{0}C, at 19 ^{0}C there appeared to be net heat gain suggesting decreased heat loss from the horse. Lindner et al [9] took rectal temperatures of their horses before and after trotting in water at 22 °C. In all water depths used, rectal temperatures increased from pre-exercise levels. Typically used water temperatures for horses walking in water are cooler (13-22 °C) than for dogs (~ 30 °C [27] and humans (28-36 °C) [14] walking in water. Water temperature should be considered when heart rate is used to estimate workload.

Blood lactate is commonly used as an indicator of the anaerobic contribution to exercise [15]. Blood lactate levels have been measured during WT exercise [9, 16]. Peak blood lactates did not reach 3.0mmol/l in horses trotting in water depths from 10-80% of wither height [9] and plasma CK levels remained under 80U/l. The authors concluded that the muscles were working aerobically and there was no indication of muscle damage following trotting in water.

A group in Hungary investigated the effect of WT exercise on lactate, lactate dehydrogenase, CK, asparate aminotransferase, glucose, cholesterol, triglyceride, total bilirubin and cortisol [16]. Eight show jump trained horses had three WT exercise sessions incorporated into their training program for one week. Each WT session consisted of 10 minutes walking (1.3 m/s), 30 minutes trotting (3.6 m/s) and then 4 minutes walking (1.3 m/s). The water temperature was 22°C at a height of 15 cms above the shoulder joint throughout exercise. None of the variables measured indicated that the WT exercise constituted high intensity exercise although the cortisol levels were elevated. The authors suggest that the elevated cortisol levels during WT exercise of up to 246 nmol/l indicated that WT exercise 'posed a stress situation' to the horses, but the values are not dissimilar to normal resting plasma cortisol (i.e. 219-396 nmol/l [17]). So all measures to date of heart rate and blood lactate support the fact that WT exercise is aerobic exercise and even after trotting in high water for up to 30 minutes there were no indications of muscle damage as indicated by CK levels.

3.2 Chronic physiological responses to water treadmill training

Despite the evidence to date demonstrating that WT exercise only constitutes moderate intensity exercise, there remains considerable motivation to uncover possible training benefits as anecdotal claims suggest that WT exercise elicits an equivalent (or perhaps even greater) training stimulus at lower speed and lower weight bearing than some 'equivalent' exercise overland. To date, only two studies by the same research group [10, 18] have considered the physiological responses of horses to WT training, as a result of four and eight weeks WT training respectively. Neither study supported an effect of increasing either stamina or power at greatly reduced training speeds. In Borgia et al's study [10], five unfit horses (having had no structured exercise for 12 months prior to the study) were trained on a WT five days per week for four weeks, starting with five minutes per day and finishing with 20 minutes per day. Horses walked in water at the level of the ventral abdomen at 2.0 m/s (considerably quicker than many other studies typically use for walk). The programme was taken from the manufacturer's recommended programme for 'bowed tendon rehabilitation'. Pre- and post-training V_{200} tests were performed on a land treadmill and resting gluteal (GM) and superficial digital flexor (SDF) muscle biopsies were taken for biochemical analyses. The authors found no improvement in V_{200} as a result of this programme nor any improvement in oxidative capacity of GM or SDF. Plasma CK was within normal ranges throughout the entire training period. They concluded that there were no demonstrable circulatory or skeletal muscle training effects during four weeks training using the programme recommended by the manufacturer for tendon rehabilitation. A different study from the same group [18] measured fibre properties and metabolic responses of the GM and SDF muscles following eight weeks of training in which six horses either walked on a land treadmill or walked on a WT for up to 40 minutes per day, five days per week in a randomised crossover design, with a 60 day detraining period in between the two protocols. No training adaptation in terms of muscle fibre composition, type II fibre diameter, muscle analyte concentrations, blood lactate concentrations or heart rate responses were seen with either type of training. The authors concluded that after rehabilitation using WT exercise, horses would need to undergo standard overland fitness training. They concluded that to put a horse straight into gallop training following a WT programme would risk fatigue of the SDF muscle and tendon injury.

There is some evidence in humans and dogs that WT exercise may be useful in a training programme targeted at weight loss. Greene et al [19] carried out a study of the comparative efficacy of land treadmill and WT training for overweight or obese human adults. In this study, efforts were made to ensure equivalent intensities and durations of exercise were compared by calculating the equivalent energy expenditure for each type of exercise. Water was at chest level and increasing jet resistance was used effectively as a means of increasing WT intensity rather than running speed. The mean VO_{2max} of the 55 participants increased significantly (by 3.6 ± 0.4 ml/O_2/kg) as a result of both types of training but WT training was more effective at increasing lean leg mass and also lean total body mass compared to the land treadmill programme. Given that both methods of training had the desired responses in terms of increasing VO_2, reducing bodyweight, body mass index, body fat percentage and fat mass, the authors suggest that WT training might have additional benefits for overweight/obese patients with respect to the reduction in ground reaction forces during exercise and the potential for increased lean leg mass; the latter possibly due to increased muscular force requirements of WT exercise. An exercise programme incorporating WT exercise has been investigated as part of a three month weight loss programme in dogs [20]. Dogs were walked in elbow depth water approximately once a week. With each successive examination there was a decrease in weight, as well as thoracic and abdominal circumferences. However, this study did not apply any type of control exercise programme for comparison. This could potentially be applicable to the leisure or show horse where obesity may be a problem. For sport horses, where obesity is less likely to be a problem, there is a drive towards finding exercise that reduces the risk of repetitive strain injury, whilst allowing full ROM and muscle function. Studies evaluating possible protective effects of incorporating WT exercise into the training programmes of sport horses would have potential benefit.

3.3 Muscle activity and duration during water treadmill exercise

Electromyography (EMG) is used for a variety of clinical and experimental studies [21] even though EMG use during WT exercise is challenging as most equipment is not built to operate in water [22]. Studies in humans suggest that muscle activity in water is lower than on dry land for any given force output although the mechanism for this is not yet fully understood [19]. Muscle activity was lower during water walking than on dry land in healthy young adults when walking at similar levels of exertion as measured using heart rate [23]. However, when muscle activities at equivalent speeds are compared in water and on dry land, muscle activities are greater in water than on dry land, presumably to overcome the drag force while walking in water. The authors indicated that water will also affect muscle activity differently depending on the role of the muscle. Muscles responsible for weight bearing have a reduced energy requirement in water and those responsible for propulsion have a greater energy requirement (dependent upon walking speed and level of immersion).

The only published study to date investigating EMG activity in horses during WT exercise was carried out by Tokuriki et al [24] by using fine wire EMG to observe muscle activity patterns in the forelimbs of six horses when exposed to walking on land, swimming, and walking and trotting on a WT. *Brachiocephalicus* (a forelimb protractor) showed its highest activity during swimming followed by walk and trot in the WT and then walking overland. *Extensor digitorum communis* had a higher EMG intensity in walk on the WT than in other type of locomotion. The authors concluded that walking on the WT required more intense muscle activity of the forelimb than trotting on the WT. There are two explanations for this, the drag experienced when walking quickly in water is greater than when trotting slowly (during trot the horse has more vertical displacement, effectively reducing the amount of limb immersed in the water), and secondly in trot, the hindquarters begin to contribute more of the energy required for propulsion. S*emitendinosus* activity during WT exercise has been studied, with muscle activity being inferred using infrared thermography [25]. Increasing water depth was found to have no effect on *semitendinosus* activity, although whether skin surface temperature changes are sensitive or specific enough to determine the activity of a particular underlying muscle is not clearly confirmed, so these results should perhaps be interpreted with caution. It has previously been demonstrated in the human arm that an increase in skin surface temperature is correlated with increased muscle activity [26].

4. Biomechanics of water treadmill exercise

The biomechanical responses of animals exercising on a WT are influenced by the physical properties of water. The most pertinent properties which interact to influence limb movements are drag and buoyancy, which have a significant effect on locomotion due to the limbs, and potentially the abdomen in deep water, being submerged in the water. It is therefore important to understand how they could affect biomechanical patterns in the horse. Drag (F_{drag}) is given by the formula: $F_{drag} = ½ \rho A v^2 C_D$. Where ρ is the density of the water, v is the velocity of the object relative to the fluid, C_D is the drag coefficient (a dimensionless parameter) and A is the reference area [27]. Drag increases as a function of the velocity squared and so humans and horses walk/run at considerably lower speeds on a WT than on a land treadmill. Approximately half the speed is required to produce a similar level of energy expenditure to walking on dry land [28]. The reference area, A, is the frontal plane of the horse which is submerged in water, so drag increases with water depth. The fluid density and the drag coefficient are essentially constant for any given exercise session so the speed of the belt and the water depth are the major determinants of the drag force experienced by the horse walking in water. Any body part that is immersed, displaces water and an upthrust is created which offloads the weight of the body equivalent to the volume of the water displaced. For humans, immersion to the pelvis offloads bodyweight by 40% or more, but for quadrupeds immersion up to the same level offloads the bodyweight to 60% or more [29, 30]. Horses in water would therefore be expected to walk slower with patterns influenced by water height and alterations in effective body weight.

4.1 Limb kinematics

Both drag and buoyancy increase with water depth, and so whilst an increase in water depth impedes forward movement of a limb, buoyancy assists upward movement of a limb [31]. Stride features, such as stride length and frequency, on a WT are therefore expected to be quite different to those seen overland due to the effect of drag and bouyancy. However, to date there are no published studies directly comparing WT and overland movement patterns in the same group of horses.

A typical overland walk with a speed of 1.2-1.8 m/s has a stride frequency of 0.8-1.1 strides/s and a stride length ranging from 1.5-1.9 m [32]. It has been shown that stride frequency was lower when walking at 0.9m/s in deep water (carpal depth and above) compared to walking in coronary band depth water (0.57 strides/s compared to 0.52 strides/s) and stride length was greater (1.5 m to 1.7 m) [2]. It is interesting to note that whilst the speed and stride frequency of the walk in this study were about half that of an overland walk, the stride length was comparable once the water was at carpus depth and above. The selection of a relatively longer, slower stride pattern in higher water is associated with a reduction in stance duration and an increase in swing duration compared to walking at lower depths [33]. The stride pattern adopted during water walking therefore has potential for the training of dressage horses as these gait characteristics (i.e. increased stride length and decreased stride frequency) are desirable [34].

Studies in dogs [35] and horses [33] have shown that water depth can have a significant effect on joint range of movement (ROM). In walking dogs [35, 36] the maximum ROM of the tarsal, stifle and hip joints is seen in water at the level of the stifle joint, and these ROM's are greater than when water is at lower (tarsal joint) or higher (greater trochanter) depth. A similar pattern was detected in walking horses where the greatest ROM of the carpus was seen with water at hock depth, and the greatest ROM of the hock was seen in stifle depth water [33]. Increases in ROM of the distal limb joints as water depth increases are reflected in increased pelvic vertical displacement [37, 38] in walk and trot [39]. Proximal and distal limb joint ROM of horses walking in water at the level of the hip, and limb joint ROM in any depth of water during trot have yet to be measured.

4.2 Thoracolumbar kinematics

Experimentally-induced lameness in horses has been shown to alter back kinematics [40, 41]. As alterations in water depth affect limb movement and stride characteristics it is reasonable to assume that changes in water depth will induce changes in back and pelvic movement. Anecdotally, WT exercise in horses is reported to promote flexion of the back, a claim which is supported to an extent by the findings from two separate studies on back movement during WT walking. The first [37] measured flexion of the lumbosacral region of the spine (referred to as pelvic flexion), axial rotation (rotation around the craniocaudal axis) and lateral bend (rotation around the dorsoventral axis) with increasing water depths and also the effects of repeated WT exercise (4 sessions over 10 days) using videography. Pelvic flexion increased with water depth, contributing to the increase in stride length observed earlier [2]. The greatest axial rotation was seen in carpal depth water and lateral bend decreased significantly from control to shoulder. There was no significant difference in any of the variables measured between day 1 and day 10, and so it appears that a short 10 day training period (including just four treadmill sessions) does not induce any measurable adaptation in back movement. As the horses had no prior experience of WT exercise, there may have been interaction of habituation and training effects over the course of the 10 days, so measurements of back kinematics over longer training periods would be useful, to investigate if pelvic flexion and stride length are altered over time as a result of potential changes in joint mobility or muscle adaptation.

Water treadmill exercise is often recommended following conservative or surgical treatment for over-riding dorsal spinous processes based on the rationale that increased distal limb ROM will enhance back flexion. However recent work shows that WT exercise does not promote flexion in all regions of the back [38]. Whilst increasing water depth from the hoof to the stifle results in greater flexion-extension ROM of the thoracolumbar spine the thoracic and lumbar spine react differently. In the cranial thoracic spine, extension increases with increasing water depth, whilst in the caudal lumbar spine, flexion increases with increasing depth. As water reaches the level of the abdomen, flexion of the caudal thoracolumbar spine may be assisted by the effect of buoyancy on the trunk due to an increase in the submerged surface area of the horse's body. Increased extension of the thoracic spine may be due to the inability of the horse to lower the head as water level is raised [42].

The results of the equine kinematic studies [2, 33, 37, 38, 39] indicate that water depth has a significant effect on movement patterns of the limbs, back and pelvis. There appear to be no trends in movement pattern over short training periods (up to 10 days) but the nature of the changes in limb movement [33] and back posture [38, 39] may have significant application within the training and rehabilitation programmes of horses depending on the individual requirements. Further work is required to determine if WT training has any influence on movement patterns overland when incorporated into a training or rehabilitation programme.

5. Rehabilitation

It appears from the literature that WT exercise may be a useful tool in the management of osteoarthritis in human patients in reducing pain and increasing joint mobility [43, 44]. Humans with osteoarthritis of the knee and hip joints have decreased postural stability indicated by increased postural sway [26]. One equine study has directly compared the effect of WT vs land treadmill on postural sway in horses with surgically induced osteoarthritis [45]. WT exercise was carried out in shoulder depth water. The results indicated that WT exercise reduced postural sway compared to land treadmill exercise which the authors attributed to WT exercise activating the motor neuron pool for the muscles that stabilise the limbs, thus improving balance and postural stability. This suggests that for suitable cases WT exercise could potentially be used for horses requiring improvements in balance and postural stability under the advice from a veterinarian and physiotherapist.

Work carried out in dogs [14, 29] shows that immersion in water reduces the weight borne by the limbs and that the amount of weight carried by the thoracic and pelvic limbs changes with water depth. Levine et al [29] determined that the vertical ground reaction forces significantly decreased by 9% when dogs were immersed to the level of the tarsus, 15% at the level of the stifle and 62% when immersed to hip level. The dogs placed 64% of their weight on the thoracic limbs before immersion and when they were immersed to the level of the tarsus and stifle. However 71% of the weight was carried by the thoracic limbs when immersed to the level of the hip, a phenomenon which may well occur in horses but would need to be measured. Information in this area is lacking in the equine field, and requires investigation as this could have implications when designing rehabilitation programmes where reduced weight bearing exercise is indicated.

WT exercise is used as a rehabilitation tool for a variety of problems in dogs [35, 36]. It appears that WT exercise, as part of a high-intensity programme, can prevent muscle atrophy, build muscle mass, increase joint ROM and significantly increase survival rates compared to dogs in a low-intensity programme. In practice, rehabilitation usually employs a number of treatment tools so most WT studies are limited by the lack of separation from other rehabilitation tools. The majority of canine studies suggest that WT exercise for the rehabilitation of musculoskeletal injury should not be used in isolation but as part of a treatment programme.

6. Future work

Effects of speed on joint ROM's at fixed water depths in both walk and trot with direct comparison to overland and/or land treadmill exercise would be useful for ascertaining the suitability of WT exercise for a wide range of applications. Studies which seek to investigate the effects of longer term (weeks rather than days) utilisation of WT exercise on biomechanical variables and muscle activity within the training programmes of sport horses are also needed.

Questionnaire-based information has indicated that WT exercise is frequently used in horses rehabilitating from a number of orthopaedic conditions (Tranquille *et al.,* unpublished data); however there is no scientific evidence to support the protocols currently being used. Studies investigating the value of WT exercise in the rehabilitation of specific orthopaedic conditions are warranted.

7. Conclusions

Walking on a WT is profoundly different in terms of physiology and biomechanics to walking overland or on a land treadmill. The literature describes horses both walking and trotting in high water without apparent ill-effect, and with heart rates and blood lactates indicative of aerobic exercise. Gait patterns during walk include many of the characteristics that are desirable in riding horses, such as reduced stride frequency, increased stride length and increased joint ROM, although further work on the biomechanics of trot are needed. To date, there is no evidence that horses that carry out WT exercise as part of a training programme exhibit altered or improved overland gait as a result.

Further work is required to compare WT and overland locomotion patterns, determine the short-term and long-term effects of WT exercise on overland locomotion patterns and to determine the value of WT exercise for the rehabilitation of orthopaedic conditions in the horse.

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Figure legends

Figure 1. Front view of a horse walking in stifle depth water in the equine water treadmill at the Equine Therapy Centre at Hartpury College.

Figure 2. An image from above of a horse walking in stifle depth water in the equine water treadmill at the Equine Therapy Centre at Hartpury College.